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Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

PATENT APPLICATION FEE DETERMINATION RECORD

Application or Docket Number

CALA-073100

CLAIMS AS FILED - PART I

SMALL ENTITY OR

OTHER THAN
SMALL ENTITY

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)
BASIC FEE (37 CFR 1.16(a))		
TOTAL CLAIMS (37 CFR 1.16(c))	47 minus 20 =	* 27
INDEPENDENT CLAIMS (37 CFR 1.16(b))		minus 3 = *
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(d))		

RATE	FEE
	\$345
x \$9 =	243
x 9 =	
+ =	
TOTAL	588

RATE	FEE
	\$
x \$ =	
x =	
+ =	
TOTAL	

* If the difference in column 1 is less than zero, enter "0" in column 2

CLAIMS AS AMENDED - PART II

SMALL ENTITY OR

OTHER THAN
SMALL ENTITY

AMENDMENT A	CLAIMS REMAINING AFTER AMENDMENT (Column 1)	HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)
Total (37 CFR 1.16(c))	*	Minus **	=
Independent (37 CFR 1.16(b))	*	Minus ***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(d))			

RATE	ADDI-TIONAL FEE
x \$ =	
x =	
+ =	
TOTAL	
ADDIT. FEE	

RATE	ADDI-TIONAL FEE
x \$ =	
x =	
+ =	
TOTAL	
ADDIT. FEE	

AMENDMENT B	CLAIMS REMAINING AFTER AMENDMENT (Column 1)	HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)
Total (37 CFR 1.16(c))	*	Minus **	=
Independent (37 CFR 1.16(b))	*	Minus ***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(d))			

RATE	ADDI-TIONAL FEE
x \$ =	
x =	
+ =	
TOTAL	
ADDIT. FEE	

RATE	ADDI-TIONAL FEE
x \$ =	
x =	
+ =	
TOTAL	
ADDIT. FEE	

AMENDMENT C	CLAIMS REMAINING AFTER AMENDMENT (Column 1)	HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)
Total (37 CFR 1.16(c))	*	Minus **	=
Independent (37 CFR 1.16(b))	*	Minus ***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(d))			

RATE	ADDI-TIONAL FEE
x \$ =	
x =	
+ =	
TOTAL	
ADDIT. FEE	

RATE	ADDI-TIONAL FEE
x \$ =	
x =	
+ =	
TOTAL	
ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

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VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS
37 CFR 1.9(f) AND 1.27(f) - SMALL BUSINESS CONCERN

I hereby certify that I am an official of the small business concern empowered to act on behalf of the concern identified below:

Calabazas Creek Research
20937 Comer Drive
Saratoga, Ca. 95070

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18 and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time, or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that the rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled:

Electron Gun for a Multiple Beam Klystron
using Magnetic Focusing

by inventors R. Lawrence Ives and George Miram, described in the specification attached herewith.

If the rights held by the above identified small business concern are not exclusive, each individual, concern, or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit Organization under 37 CFR 1.9(e). *NOTE: Separate verified statements are required from each named person concern or organization having rights to the invention referring to their status as small entities. (37 CFR 1.27)

Name: _____

Address: _____

☐ Individual ☒ Small Business ☐ Nonprofit Organization

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which the status as a small entity is no longer appropriate (37 CFR 1.28(b)).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge and willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING: R. Lawrence Ives
ORGANIZATION: Calabazas Creek Research
TITLE IN ORGANIZATION: President
ADDRESS OF PERSON SIGNING: 20937 Comer Drive
Saratoga, Ca. 95070

Signature R. Lawrence Ives

Date 7/13/00

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ELECTRON GUN FOR A MULTIPLE BEAM KLYSTRON USING MAGNETIC
FOCUSING

Field of the Invention

The present invention relates to linear beam electron
devices, and more particularly, to an electron gun that
provides multiple convergent electron beamlets suitable for
use in a multiple beam klystron using confined flow
magnetic focusing.

Background of the Invention

Linear beam electron devices are used in sophisticated
communication and radar systems that require amplification
of a radio frequency (RF) or microwave electromagnetic
signal. A conventional klystron is an example of a linear
beam electron device used as a microwave amplifier. In a
klystron, an electron beam is formed by applying a voltage
potential between a cathode emitting electrons and an anode
accelerating these emitted electrons such that the cathode
is at a more negative voltage with respect to the anode.

1 The electrons originating at the cathode of an electron gun
2 are thereafter caused to propagate through a drift tube,
3 also called a beam tunnel, comprising an equipotential
4 surface, thereby eliminating the accelerating force of the
5 applied DC voltage. The drift tube includes a number of
6 gaps that define resonant cavities of the klystron. The
7 electron beam is velocity modulated by an RF input signal
8 introduced into the first resonant cavity. The velocity
9 modulation of the electron beam results in electron
10 bunching due to electrons that have had their velocity
11 increased gradually overtaking those that have been slowed.
12 Velocity modulation in the gain section of the tube leads
13 to bunching, i.e. the transformation of the electron beam
14 from continuously flowing charges to discrete clumps of
15 charges moving at the velocity imparted by the beam
16 voltage. The beam bunches arrive at the bunching cavity,
17 sometimes called the penultimate cavity, where they induce
18 a fairly high RF potential. This potential acts back on the
19 beam, and serves to tighten the bunch. When the bunches
20 arrive at the output cavity they encounter an even higher
21 rf potential, comparable to the beam voltage, which
22 decelerates them and causes them to give up their kinetic
23 energy. This is converted to electromagnetic energy and is
24 conducted to a load. The tighter the bunching, the higher

1 the efficiency. However, a high degree of space charge
2 concentration interferes with the bunching process and the
3 efficiency. Other things being equal, the higher the
4 perveance of a klystron, the lower the efficiency.

5 The effect of perveance on the gain of a klystron is
6 different. Although the gain is affected by space charge,
7 it is a stronger function of the total current, which is
8 proportional to the perveance. This suggest that if a beam
9 cross-section were made larger, so that the current density
10 and space charge are reduced, both gain and efficiency
11 would benefit. However, such is not the case because a
12 large beam requires a large drift tube, and the electric
13 fields which couple the beam to the circuit fall off across
14 the beam, leading to poor coupling and a drop in both gain
15 and efficiency. A small beam is therefore necessary, but if
16 the power output required is high, the voltage, rather than
17 the current in the beam must be increased for reasonable
18 efficiency.

19 Bandwidth is inversely proportional to the loaded Q_s
20 of the klystron cavities. In the gain section of the tube,
21 where cavities are stagger-tuned, the cavity Q_s are loaded
22 by the beam. The higher the current, the higher the
23 loading, and consequently the lower the Q . It does not
24 matter if a single beam or several beams are traversing the

1 cavity. The output cavity, in particular, must by itself
2 have a bandwidth at least equal to the desired bandwidth of
3 the klystron. For the output cavity to produce good
4 efficiency, this bandwidth becomes proportional to the beam
5 conductance. However this leads to higher perveances, and
6 hence lower efficiency. Consequently, in a single beam
7 klystron the efficiency/bandwidth product is approximately
8 constant.

9 Given the preceding relationships, the advantage of
10 the multiple beam klystron provides is clear. The current
11 is divided into several beams, each with a low space
12 charge, so that it can be bunched tightly in a small drift
13 tube with good coupling coefficient, and hence high
14 efficiency. The gain-bandwidth product is not constant, but
15 increases with the addition of beams. For the same power
16 and gain, the multiple beam klystron is shorter than a
17 conventional klystron.

18 Despite the potential advantages of multiple beam
19 klystrons, such devices have only been adapted for certain
20 low power or low frequency applications in which a
21 convergent electron beam is not necessary. In these
22 nonconvergent devices, electron beam focusing is provided
23 by immersing the electron gun and drift tubes in a strong
24 magnetic field which guides the electrons along the

1 magnetic flux lines to the drift tubes. In a nonconvergent
2 electron gun, the diameter of the emitting surface is the
3
4 same as the electron beam that propagates through the RF
5 device. The nonconvergent electron beams of this class of
6 device have limited current density, which prevent them
7 from developing more power at higher frequencies. The
8 amount of current that can be emitted from the cathode is
9 dependent on the size of the emitting surface and the
10 maximum electron emission density that can be provided by
11 the surface. Maximum electron emission densities from
12 typical cathodes operating in the space charge limited
13 regime are on the order of 10-20 amps/cm².

14 In a convergent electron gun, the cathode diameter
15 exceeds the diameter of the final electron beam, which
16 means that more current can be provided. The current gain
17 is proportional to the area compression factor of the gun,
18 which is the ratio of the cathode area to the cross
19 sectional area of the final electron beam. Typical
20 compression factors are 5-20.

21 Electron beams used for linear RF devices typically
22 employ one of two types of magnetic focusing, which act in
23 addition to the initial electrostatic focusing of a Pierce
24 electron gun, whereby a stream of emitted electrons is

1 initially focused to a region of minimum beam diameter.
2 The first type of magnetic focusing is Brillouin focusing,
3 where the magnitude of the magnetic field in the circuit
4 section of the device precisely balances the space charge
5 repulsion forces within the static beam. An embodiment of
6 such a device is shown in Figure 1. Electrostatic focusing
7 is used to guide the electron beam from the cathode
8 emitting surface to a point within the anode beam tunnel. A
9 minimum diameter is achieved, and if a counteracting
10 magnetic field were not applied, the beam would begin to
11 diverge due to space charge forces. In Brillouin
12 magnetically focused devices, an axial magnetic field is
13 imposed at the location of the minimum diameter that
14 balances the space charge forces and facilitates transport
15 of the beam through the device.

16 Unfortunately, the balance between the space charge
17 force tending to expand the beam and the magnetic force
18 tending to confine the beam is no longer equal when
19 electrostatic bunching of electrons occurs, as is required
20 to transform beam power into RF power. Consequently, the
21 beam will expand in regions of high electron density,
22 eventually resulting in impact of electrons with the walls
23 of the beam tunnel. This can result in destruction of the
24 device unless the power deposited is limited. Therefore,

1 Brillouin focused devices are limited in the average RF
2 power and pulse lengths that can be generated.

3 The alternative is to use convergent, confined flow
4 focusing, as shown in Figure 2. With confined flow
5 focusing, the magnetic field encompasses the cathode
6 regions of the device where the electron beam is generated.
7 A combination of magnetic and electrostatic focusing is
8 used to guide the electron beam from the cathode into the
9 beam tunnel. With confined flow focusing, the magnetic
10 field can be higher than is required for balancing the
11 space charge forces in the static beam. In typical devices,
12 the magnetic field is 2-3 times the Brillouin value. With
13 confined flow focusing, the convergent electron beam will
14 be contained as it traverses the beam tunnel, even in the
15 presence of electron bunching as used to generate RF power.
16 Consequently, confined flow focused devices are capable of
17 high average power operation.

18 In typical single beam devices, the magnetic field is
19 generated from a solenoid or permanent magnet symmetrically
20 located with respect to the electron beam, which produces a
21 magnetic field that is radially symmetric about the
22 electron beam, which is typically located on the main axis
23 of the device. This radially symmetric field is necessary
24 for the electron beam to follow its non-divergent axial

1 path. The magnitude and shape of the field in the cathode-
2 anode region is controlled using an iron enclosure around
3 the main solenoid or permanent magnet with an aperture
4 through end plates perpendicular to the device axis,
5 allowing field penetration into the cathode-anode region.
6 Auxiliary coils or permanent magnets may also be used in
7 the cathode-anode region to control the shape and magnitude
8 of the field.

9 While this works well for single beam devices having a
10 beam tunnel symmetrically located with respect to the
11 magnetic field axis, problems occur for electron guns where
12 the cathode-anode region is radially displaced from the
13 device axis. A radial gradient, or shear, in the magnetic
14 field in the cathode-anode region distorts the magnetic
15 focusing, preventing operation of the device. In order to
16 realize a multiple beam device, it is necessary for most
17 cathode-anode structures to be radially displaced from the
18 device axis.

19 In light of these limitations, the need for a high
20 power, multiple beam klystrons with confined flow focusing
21 for use with high frequency RF sources is clear.

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Related Art

A device described by Symons [5,932,972] provides for a convergent multiple beam gun having a single cathode, a first plurality of conductive grids, a second plurality of drift tubes further containing resonant gaps, and an anode. The first plurality of conductive grids are spaced between the cathode and drift tubes, and contain apertures in locations such that electron beamlets are formed and defined by electrons traveling from the cathode, through the apertures in each of the grids, and into the drift tubes. Each of the grids has these apertures in substantial registration with each other and with respective openings of the plurality of drift tubes.

Symons relies on a plurality of grids to shape the electric potentials to focus the individual beamlets into the respective drift tunnels. In one embodiment of the invention, four separate grids are required to provide the necessary electric field configuration. Ceramic insulators providing a portion of the vacuum envelope of the device must electrically isolate each grid. In addition, a separate voltage is required for each grid.

1 The device described by Symons does not provide for
2 confined flow focusing, as it can be seen that no magnetic
3 focusing field is applied, and beam focusing is performed
4 entirely by electrostatic potentials applied to the many
5 grids. Consequently, the beam will not be fully confined in
6 the presence of space charge bunching, limiting the average
7 and peak power capability of the device. Further, the
8 device described by Symons applies only to fundamental mode
9 cavities, which limits the frequency at which this
10 technique can be applied.

11 As the RF frequency increases, the available space for
12 multiple beams through a fundamental mode cavity decreases
13 in proportion to the increase in frequency. Consequently,
14 the number of beams that can propagate through a
15 fundamental mode cavity becomes limited by mechanical and
16 thermal constraints. An alternative is to use a ring
17 resonator circuit as described by Bohlen (U.S. Patent No.
18 4,508,992). With a ring resonator circuit, the number of
19 beamlets is not strictly limited by frequency
20 considerations. Bohlen describes a microwave amplifier
21 having an annular cathode, an annular ring resonator for
22 the introduction of RF energy, an annular ring resonator
23 for the removal of RF energy, and an annular collector, all
24 of which are operating in the presence of a magnetic field.

1 This structure enables reduced current densities and the
2 application and collection of RF energy over a large
3 physical area. A disadvantage of this structure is that
4 the annular beam tunnels can allow transmission of higher
5 order cavity modes back toward the electron gun. These
6 modes can lead to undesired bunching of the electron beam
7 and prevent operation at the desired frequency and power.
8 Consequently, the gain of this device is limited to less
9 than 25, and the output power level is limited to a few
10 megawatts.

11 A multiple beam device using periodic permanent magnet
12 focusing was described by Caryotakis et al (European patent
13 WO 97/38436). This device uses periodic permanent magnet
14 (ppm) focusing. PPM focusing uses an array of permanent
15 magnets with alternating magnetic orientations to produce a
16 focusing magnetic field. The focusing field produced by PPM
17 focusing is axial, as in solenoidal focusing, but
18 alternates direction, unlike solenoidal focusing. PPM
19 focusing has been used for years for beam focusing in
20 traveling wave tubes. The focusing described by Caryotakis
21 only applies to beam confinement within the body or circuit
22 section of the device and is not applicable to the electron
23 gun region. Further it requires a series of cylindrical
24 permanent magnets around each individual beam tunnel. Since

1 these magnets can not tolerate high temperatures, they must
2 be applied after construction of the vacuum envelope of the
3 rf device. High power operation of rf devices requires
4 processing in ovens operated at 400-500 degrees C in order
5 to obtain sufficient vacuum for operation. Consequently,
6 each beam tunnel must contain its own individual vacuum
7 envelope to provide access for the PPM magnets.

8 Since the device proposed by Caryotakis does not
9 address the magnetic focusing in the electron gun, the
10 present invention could be adapted to work in conjunction
11 with the device described by Caryotakis.

12 13 Summary of the Invention

14
15 In view of the limitations of the prior art, the
16 present invention provides for an RF device having
17 convergent multiple beams for use in high frequency, high
18 power RF generators, such as multiple beam klystrons or
19 inductive output tubes (IOT). This device has a plurality
20 of drift tubes for the transport of multiple convergent
21 beamlets in a rectilinear flow. Each drift tube carries an
22 electron beam formed by an individual electron gun, and a
23 plurality of these electron guns is arranged in a circular
24 ring, with each electron gun providing a beam for use by an

1 associated drift tube. Each electron gun has a cathode, an
2 electrostatic focusing electrode and anode structure. The
3 path of the confined flow of electrons from each electron
4 gun through the drift tubes of the device forms a beam
5 tunnel, and each separate gun has its own separate beam
6 tunnel. Gaps between drift tubes form resonant cavities
7 for the introduction and removal of RF power and for
8 increased bunching of the electron beam. The RF power
9 introduced into an input port of the device operates on
10 each individual beamlet traveling through each individual
11 beam tunnel, and RF power extracted at the output port is
12 summed by the RF output structure. In the context of the
13 present device, a high power composite electron beam is
14 formed which comprises the contribution of each individual
15 beamlet, so the output power of the device is limited only
16 by the number of beamlets that are contributing to the RF
17 output port. While the beamlets formed by each electron gun
18 travel through separate beam tunnels, the anode structure
19 and cathode structure for each gun may be separate, or it
20 may be shared.

21 In one embodiment of the invention, the beam tunnels
22 for each electron beam include drift tubes having a first
23 resonant cavity defined by a first gap provided in the
24 plurality of drift tubes, and a second resonant cavity

1 defined by a second gap provided in the plurality of drift
2 tubes. An electromagnetic signal is coupled into an RF
3 input port to the first resonant cavity, which velocity
4 modulates the beamlets traveling in the plurality of drift
5 tubes. The velocity modulated beamlets then induce an
6 electromagnetic signal into the second resonant cavity,
7 which may then be extracted from the device RF output port
8 as a high power microwave signal. Other resonant cavities
9 may also be applied between the first and final resonant
10 cavity to increase the gain, bandwidth and efficieny of the
11 device. A collector is disposed at respective ends of the
12 plurality of drift tubes, which collects the remaining
13 energy of the beamlets after passing across the various
14 cavities. A magnetic field oriented coaxially to the beam
15 tunnel is furnished to provide confined flow of the
16 electron beam.

Objects of the Invention

19 A first object of the invention is a multiple beam
20 device for the amplification of Rf power having a plurality
21 of electron beam tunnels, each said tunnel carrying an
22 electron beam formed by an electron gun. The multiple beam
23 device consists of the following elements:

1 a plurality of drift tubes, the drift tubes separated
2 to form a plurality of gaps associated with resonant
3 cavities, including a first gap for the introduction of RF
4 energy through an RF input port, and a final gap for the
5 removal of RF energy through an RF output port,

6 an anode for the acceleration of electrons,

7 a magnetic field generator producing a radially
8 symmetric field along a common axis defined by the beam
9 tunnels,

10 and a plurality of magnetic field correctors for
11 producing a magnetic field which is radially symmetric
12 through each individual beam tunnel.

13 A second object of the invention is a multiple beam
14 device having a plurality n of electron guns, each electron
15 gun providing an electron beam traveling through an
16 electron beam tunnel between a cathode and a beam
17 collector, a common magnetic field applied to the beams of
18 all n electron guns, individual magnetic field correctors
19 applied to each individual gun, an RF input port, and an RF
20 output port.

21 A third object of the invention is a multiple beam
22 device having an input RF port and an output RF port common
23 to all electron beamlets.

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3 Brief Description Of The Drawings

4 Figure 1 is a schematic of a prior art Brillouin
5 focused electron gun.

6 Figure 2 is a schematic of a prior art confined flow
7 electron gun.

8 Figure 3 is a section view of a prior art single beam
9 klystron with a magnetic circuit.

10 Figure 4 is a section view of a multiple beam klystron
11 showing individual electron guns creating a multiplicity of
12 beamlets. Also shown is the magnetic circuit for focusing
13 of the individual convergent multiple beams.

14 Figure 4-1, detail shows the detail of a beam tunnel
15 having drift tubes and resonant gaps.

16 Figures 4a through 4c is are sections a-a, b-b, and c-
17 c through figure 4.

18 Figure 5 is a section view of the electron gun shown
19 in Figure 4.

20 Figure 6a is a three dimensional view of the magnetic
21 circuit of Figure 4 showing an electromagnetic coil and
22 shaped iron structure in the gun region for reducing radial
23 and azimuthal asymmetries at the cathode locations.

1 Figure 6b is the cross section of the uncorrected
2 magnetic field and the envelope of the electron beam
3 produced by an uncorrected off-axis electron beam of figure
4 6a.

5 Figure 6c is the cross section of the corrected
6 magnetic field and the envelope of the electron beam
7 produced by the configuration of figure 6a.

8 Figure 7 is an alternate embodiment of the
9 configuration of Fig. 6a with an auxiliary electromagnet or
10 permanent magnet surrounding the plurality of cathodes.

11 Figure 8 is an alternate embodiment of the
12 configuration of figure 6a with an auxiliary permanent
13 magnets surrounding the plurality of cathodes and a
14 permanent magnet interior to the plurality of cathodes.

15 Figure 9 is the device of figure 4 where permanent
16 magnets are used in place of electromagnets.

17 Figure 10 is the device of figure 4 including
18 additional magnetic material surrounding the plurality of
19 cathodes to provide additional field correction.

20

21 Detailed Description Of The Invention

22 Figure 1 shows a prior art Brillouin focused electron
23 gun. A cathode 10 provides a flow of electrons 12 past an
24 anode 16 at a positive voltage with respect to the cathode

1 to a distant collector 20. In a Pierce gun, focus
2 electrode 14 shapes the electron beam to a region of
3 minimum beam diameter 18. Without a magnetic field, the
4 self-charge of the electron beam causes beam spreading due
5 to the space charge effect as shown in the trajectory 22.
6 In Brillouin focusing, a magnetic field 24 is added which
7 is coaxial to the beam 12, and of sufficient magnitude to
8 cancel the space charge spreading, which results in the
9 constant width beam 26, as shown. This magnetic field 24
10 may be provided through the introduction of electromagnetic
11 coils or permanent magnet material and magnetic pole piece
12 28.

13 Figure 2 shows a prior art confined flow electron gun.
14 As before, a Pierce gun comprising cathode 10 and focus
15 electrode 14 produces an electron beam 12, which converges
16 to a region of minimum diameter 18, after passing anode
17 16b. The coaxial magnetic flux field 24b is provided that
18 is allowed to pass through the polepiece 28 and extend to
19 the cathode, which provides a confined flow of electrons to
20 the distant collector 20. The extension of the magnetic
21 flux field to the cathode allows for an increase in the
22 magnetic field greater than that necessary for precisely
23 balancing the space charge forces in the unbunched beam.

1 Figure 3 shows a prior art single beam klystron tube
2 90. Electron gun 100 provides a beam of initially focused
3 electrons 92, which travel through a beam tunnel 93 to
4 collector 120. The beam tunnel 93 is enclosed by
5 electromagnet 130, which produces a coaxial magnetic flux
6 field with flux lines parallel to the beam axis 91 and beam
7 tunnel 93 within the iron enclosure 140. An RF input port
8 94 couples incoming RF energy to a resonant cavity 96,
9 which velocity modulates the beam 110. A second resonant
10 cavity 98 provides additional modulation, and a third
11 cavity 103 enables the removal of RF energy through RF
12 output port 114.

13 Figure 4 shows the present invention, which provides a
14 convergent multiple beam klystron 140 having a plurality of
15 high current electron beams to permit construction of a
16 multiple beam RF device of high power and high frequency.
17 While the development of symmetric fields for radially
18 symmetric devices is simplified by the intrinsic symmetry
19 of the magnetic structures, this is not the case for
20 multiple gun, off-axis designs such as the present
21 invention of figure 4. As known in the art, conventional
22 electron guns are designed using advanced computational
23 tools to model the electrostatic potential, magnet flux
24 contours, and electron trajectories. Examples of these

1 codes include Maxwell 2D and Beam Optics Analysis (BOA)
2 from Ansoft Corporation, the three dimensional finite
3 difference program MAFIA, and the beam trajectory code
4 XGUN. These tools were used to model the present invention
5 to insure that laminar electrons beams were generated
6 suitable for a klystron or IOT RF circuit. It is clear to
7 one skilled in the art that magnetic field design tools of
8 this type are required for the optimization of specific
9 structures for use in shaping a magnetic field in the
10 present art of designing confining flow magnetic fields for
11 use in electron beam devices. For the present invention,
12 Maxwell 2D and MAFIA were used to design a magnetic
13 configuration where lines of magnetic flux intersect each
14 cathode perpendicular to the emitting surface with
15 sufficient magnitude to guide the electrons through the
16 cathode-anode region into the center of each beamlet's
17 respective beam tunnel. Maxwell 2D was also used to design
18 the electrostatic geometry providing equipotential contours
19 consistent with the desired operation. BOA and XGUN were
20 used to model electron trajectories through the cathode-
21 anode region to insure that the desired performance was
22 achieved.

23 Figures 4a, 4b, and 4c show cross section views of the
24 present invention, and may be examined in conjunction with

1 corresponding sections a-a, b-b, and c-c of figure 4. A
2 plurality n of electron guns 230a, 230b,...230n is arranged
3 circularly around a central axis Z 150. A reference plane
4 R is perpendicular to the axis Z 150, and is used in the
5 illustrations for section a-a, b-b, and c-c. Figures 4a-c
6 show a cross section view of a device where n=7. Each
7 electron gun 230a..n is arranged circularly around the
8 central axis Z and produces a beamlet which initially
9 focuses to a minimum diameter 106a..n, as described earlier
10 in figure 2. As is clear to one skilled in the art, other
11 non-circular and irregular inter-gun spacings can be used,
12 but the regular spacings and circular arrangement is shown
13 for clarity in the drawings. Each beamlet from each
14 electron gun 230a..n travels through its own beam tunnel
15 156a..n along a beam tunnel axis 152a..n to a collector
16 112a..n. Each beamlet travels in its respective beam
17 tunnel 152a..g which has a conductive inner surface 173,
18 and the beam tunnel comprises drift tubes 133, 135, 137,
19 and 139, and a series of resonant cavities 172, 174, 176
20 formed by drift tube gaps, and shown in figure 4-1 detail.
21 These cavities are for the introduction of RF power,
22 additional modulation of the electron beamlets, and the
23 extraction of RF power, as before. The coaxial magnetic
24 flux field generator 131 comprises a coil wound around the

1 axis 150, which produces a generally uniform flux field
2 aligned with the central axis 150, as before. The
3 resonators are shown as 172, 174, 176 comprise the annular
4 ring resonators described, for example, in U.S. Patent No.
5 4,508,992 by Bohlen et al (items 1 and 2), incorporated
6 herein by reference. A key feature of the embodiment shown
7 in Fig. 4a is the presence of an iron structure 170 and
8 electromagnetic coil or permanent magnet 180, located along
9 the centerline of the device and positioned at the
10 approximate location of the individual cathodes 102. The
11 iron structure 170 and magnet 180 provide compensation for
12 the radial asymmetry of the magnetic field at the location
13 of the individual cathodes 102, as will be described later.

14 Figures 4a-c shows the sections a-a, b-b, and c-c,
15 which include beam tunnels 156a..n, and the inner surface
16 173 and outer surface 171 of resonators 174.

17 Fig. 5 shows the key elements of the individual
18 electron guns which include a thermionic emitting surface
19 102, focus electrode 104, cathode heater 106, heat shields
20 108, insulating ceramic 192, vacuum pumpout 194, and
21 insulating ceramic 195 for the heater wire feedthrough 190.

22 In the present invention as described in figures 6
23 through 10, magnetic circuits are disclosed which provide
24 for individual focusing of each beamlet to insure optimum

1 beam transport through the RF device. The magnetic circuits
2 include a series of electromagnet coils or permanent
3 magnets that provide the magnetic field and appropriately
4 placed magnetic iron structures to shape the field as
5 required by each beamlet. In particular, magnetic iron is
6 incorporated near each individual cathode to bend the
7 magnetic field lines so that they are everywhere
8 perpendicular to the emitting surface as required for
9 laminar electron flow. Magnetic iron is incorporated
10 around the main magnet coils or permanent magnets to
11 provide for proper flux leakage into the cathode-anode
12 region and to guide the electron beamlets through the
13 circuit of the RF device.

14 For some high frequency and high power applications it
15 may be convenient to employ a klystron using ring resonator
16 cavities. Ring resonator cavities allow for location of the
17 electron beamlets at a larger radius from the device axis
18 than is possible with simple fundamental mode cavities.

19 An embodiment of the magnetic circuit for the device
20 of Fig. 4 is shown in Fig. 6a. A shell of magnetic iron 140
21 encloses magnetic coils 130 that generate the main magnetic
22 field for the RF device. As is clear to one skilled in the
23 art, it would be possible to substitute a self-magnetic
24 structure such as a permanent magnet for the coil 130 with

1 appropriate modifications to iron structure 140. Apertures
2 210 are placed in the end walls of the shell 140 to allow
3 passage of the electron beamlets and to allow magnetic flux
4 to extend into the cathode-anode regions 106 of the
5 electron guns to aid in beam focusing. An auxiliary
6 electromagnet coil or permanent magnet 180 is located along
7 the device centerline 220 and between the centerline and
8 the individual electron guns 230. In addition magnetic
9 material 170 is located along the device centerline 220 and
10 between the electron guns 230 and the centerline 220. The
11 magnetic iron 170 may include semicircular extensions 172
12 extending partially around the centerline of each
13 individual beamlet 217 to reduce azimuthal asymmetries in
14 the magnetic field at the location of the individual
15 cathodes 102.

16 Figure 6b shows a section in the RZ coordinate system
17 in the region between the magnetic polepiece end plate 140
18 and the electron gun emitter 102 where no correction is
19 made to the magnetic field using coil 180 or magnetic
20 structure 170. The figure plots contours of constant
21 magnetic field 342 emanating through aperture 210 and
22 extending to cathode 102. Note the asymmetry about the
23 cathode centerline 152 and the variation of magnetic field
24 across the emitting surface 101 of the cathode 102.

1 Electrons emitted perpendicular to surface 101 will
2 experience a magnetic field in which the direction of the
3 magnetic field vector is different from the direction of
4 electron motion, thereby imparting a transverse force on
5 the electron that will prevent proper transmission through
6 the RF device.

7 Figure 6c shows equipotential magnetic flux lines in
8 the vicinity of the electron beam aperture 210 with
9 auxiliary coil 180 and magnetic material 170. It can be
10 seen that the equipotential magnetic flux lines 336 and the
11 electron beam paths 340 are perpendicular. Thus the
12 direction of electron motion is parallel to the magnetic
13 force direction, eliminating magnetically induced forces
14 perpendicular to the direction of electron motion, which
15 causes the electron beam to experience confined flow with
16 no trajectory divergence or beam spreading.

17 An alternate embodiment is shown in figure 7, where an
18 additional field shaping electromagnet coil 232 is located
19 about the centerline of the device 220 but at a distance
20 from the centerline so as to surround the cathodes for the
21 individual beamlets. As is clear to one skilled in the
22 art, and shown in figure 8, permanent magnets 240 and 242
23 could be substituted for coils 232 and 180 of figure 7 with
24 no change in function. Field shaping electromagnet 232, or

1 180 or shaping magnet 240 or 242 would equivalently allow
2 additional control of the magnetic field in the region of
3 the electron beamlets. An alternate embodiment would
4 include an iron shield partially enclosing coil 232 on the
5 outer circumference and end to limit flux leakage into the
6 environment and reduce the power required for
7 electromagnetic coils or the field strength for permanent
8 magnets. As is clear to one skilled in the art, there are
9 many combinations of electromagnets or permanent magnets
10 which could be used to satisfy the condition of creating a
11 magnetic field which is perpendicular in gradient to the
12 electron beam trajectory over all operating regions of the
13 device.

14 Figure 9 shows the device of figure 4 wherein the iron
15 140 and magnetic coils 130 are replaced by iron 250, 251,
16 and permanent magnet 254.

17 Figure 10 shows an alternate embodiment of the
18 multiple beam device where additional magnetic material 260
19 is incorporated at a larger radius than the electron guns
20 230 and interior to outer magnetic coil or permanent magnet
21 232. The magnetic material may contain specially shaped
22 surfaces 264 to further correct the magnetic field for
23 radial or azimuthal asymmetries in cooperation with coils
24 232 and 180 and interior magnetic structure 172.

1 As shown in the alternative embodiments, the design
2 conditions which produce a magnetic field for the confined
3 flow of a plurality of radially positioned electron beams
4 are numerous. Many alternative structures could be
5 proposed which satisfy this condition, and the structures
6 given are proposed only for illustration in understanding
7 the present invention. The present RF device may operate
8 as an amplifier, or as an oscillator, or in any way a
9 single beam prior art device may operate. As vehicles for
10 understanding the present invention, it is not intended
11 that the scope of the invention is limited to only the
12 structures shown. The breadth of the invention is
13 established by the following claims:

14

1

2 We claim:

3 1) a multiple beam RF device comprising:

4 a housing having a central Z axis, said housing
5 enclosing a plurality of electron beam tunnels, each said
6 beam tunnel having a conductive inner surface, and each
7 said beam tunnel further comprising a sequence of drift
8 tubes and drift tube gaps, said beam tunnels arranged about
9 said central Z axis of said housing, and said housing
10 including a plurality of apertures, one said aperture for
11 each said electron beam tunnel;

12 a plurality of electron guns equal to said plurality
13 of said electron beam tunnels, each said electron gun
14 producing an electron beam passing uniquely through one of
15 said electron beam tunnels;

16 a magnetic field applied to each said electron beam,
17 said magnetic field having a variation of less than 5% over
18 the extent of said electron beam tunnels;

19 each said electron gun having a cathode for the
20 generation of electrons, an anode for the acceleration of
21 said electrons, and a focus electrode for the focusing of
22 said electron beams.

23

1 2) The RF device of claim 1 wherein said beam tunnels
2 are arranged substantially parallel to said central Z axis.

3 3) The RF device of claim 2 wherein RF energy may be
4 introduced in at least one of said drift tube gaps, and RF
5 energy may be removed from at least one of other said drift
6 tube gaps.

7 4) The RF device of claim 3 wherein said housing is
8 made from iron.

9 5) The RF device of claim 1 wherein said magnetic
10 field is sufficient to achieve confined electron flow.

11 6) The RF device of claim 1 wherein said magnetic
12 field produces a confining force which exceeds the space
13 charge forces in said electron beam.

14 7) The RF device of claim 6 where the magnitude of
15 said magnetic field is at least 2 times greater than said
16 magnetic field required to balance said space charge force.

17 8) a multiple beam RF device comprising:

18 a housing having a central Z axis and an R plane
19 orthogonal to said Z axis, said housing enclosing a
20 plurality of electron beam tunnels, each said beam tunnel
21 having a conductive inner surface, and each said beam
22 tunnel further comprising a sequence of drift tubes and
23 drift tube gaps, said beam tunnels arranged in said housing
24 and parallel to said central axis Z of said housing, said

1 drift tubes having a minimum separation distance from said
2 central axis Z of a separation distance D;

3 a plurality of electron guns, each said electron gun
4 producing an electron beam passing through one of said
5 electron beam tunnels;

6 a magnetic field applied to each said electron beam,
7 said magnetic field having a field variation of less than
8 5% over the extent of said electron beam tunnels;

9 each said electron gun having a cathode for the
10 generation of electrodes, an anode for the acceleration of
11 said electrons, and a focus electrode for the focusing of
12 said electron beams;

13 one or more magnetic field correctors.

14

15 9) The RF device of claim 8 wherein said magnetic
16 field corrector comprises a coil, and said extent of said
17 coil is less than said separation distance D.

18 10) The RF device of claim 8 wherein said field
19 corrector comprises a single coil and said extent of said
20 coil is greater than said separation distance D.

21 11) The RF device of claim 8 wherein said field
22 corrector comprises a first coil with an extent less than
23 said separation distance D, and a second coil with an
24 extent greater than said separation distance D.

1 12) The RF device of claim 8 wherein said field
2 corrector comprises a coil of current-carrying wire which
3 produces said correction field.

4 13) The RF device of claim 8 wherein said field
5 corrector comprises a permanent magnet.

6 14) The RF device of claim 8 wherein said field
7 corrector comprises non-magnetized iron.

8 15) The RF device of claim 9,10,11, or 12 wherein said
9 coil comprises a coil of current-carrying wire which
10 produces said correction field.

11 16) The RF device of claim 9, 10, 11, or 12 wherein
12 said field corrector comprises a permanent magnet.

13 17) The RF device of claim 9, 10, 11, or 12, wherein
14 said corrector comprises non-magnetized iron.

15 18) The RF device of claim 9, 10, 11, or 12, wherein
16 at least one of said correction coils comprises a coil of
17 current-carrying wire which produces said correction field.

18 19) The RF device of claim 9, 10, 11, or 12, wherein
19 at least one of said correction coils comprises a permanent
20 magnet.

21 20) The RF device of claim 9, 10, 11, or 12, wherein
22 at least one of said correctors comprises non-magnetized
23 iron.

1 21) The RF device of claim 8, wherein said field
2 corrector is located on the main axis of said device, said
3 field corrector has a near end in proximity to said housing
4 and intersecting said central Z axis, and a far end
5 opposite said near end, said field corrector comprising a
6 radially symmetric magnetic cylinder, said field corrector
7 having a radius which is smaller on said near end, and
8 larger at any point near said far end.

9 22) The RF device of claim 21, said field corrector
10 further including an electromagnetic coil on said smaller
11 radius.

12 23) The RF device of claim 21 or 22, said field
13 corrector further including field correcting cutouts around
14 said plurality of electron guns.

15 24) The RF device of claim 8 wherein said field
16 corrector provides a magnetic field such that equipotential
17 flux lines formed by said magnetic field when modified by
18 said field corrector are substantially parallel to said
19 electron beam tunnels.

20 25) The RF device of claim 1 or 8 wherein said RF
21 device is an oscillator.

22 26) The RF device of claim 1 or 8 wherein said RF
23 device is an amplifier.

1 Abstract

2

3 An RF device comprising a plurality of drift tubes,
4 each drift tube having a plurality of gaps defining
5 resonant cavities, is immersed in an axial magnetic field.
6 RF energy is introduced at an input RF port at one of these
7 resonant cavities and collected at an output RF port at a
8 different RF cavity. A plurality of electron beams passes
9 through these drift tubes, and each electron beam has an
10 individual magnetic shaping applied which enables confined
11 beam transport through the drift tubes.

FIGURE 1
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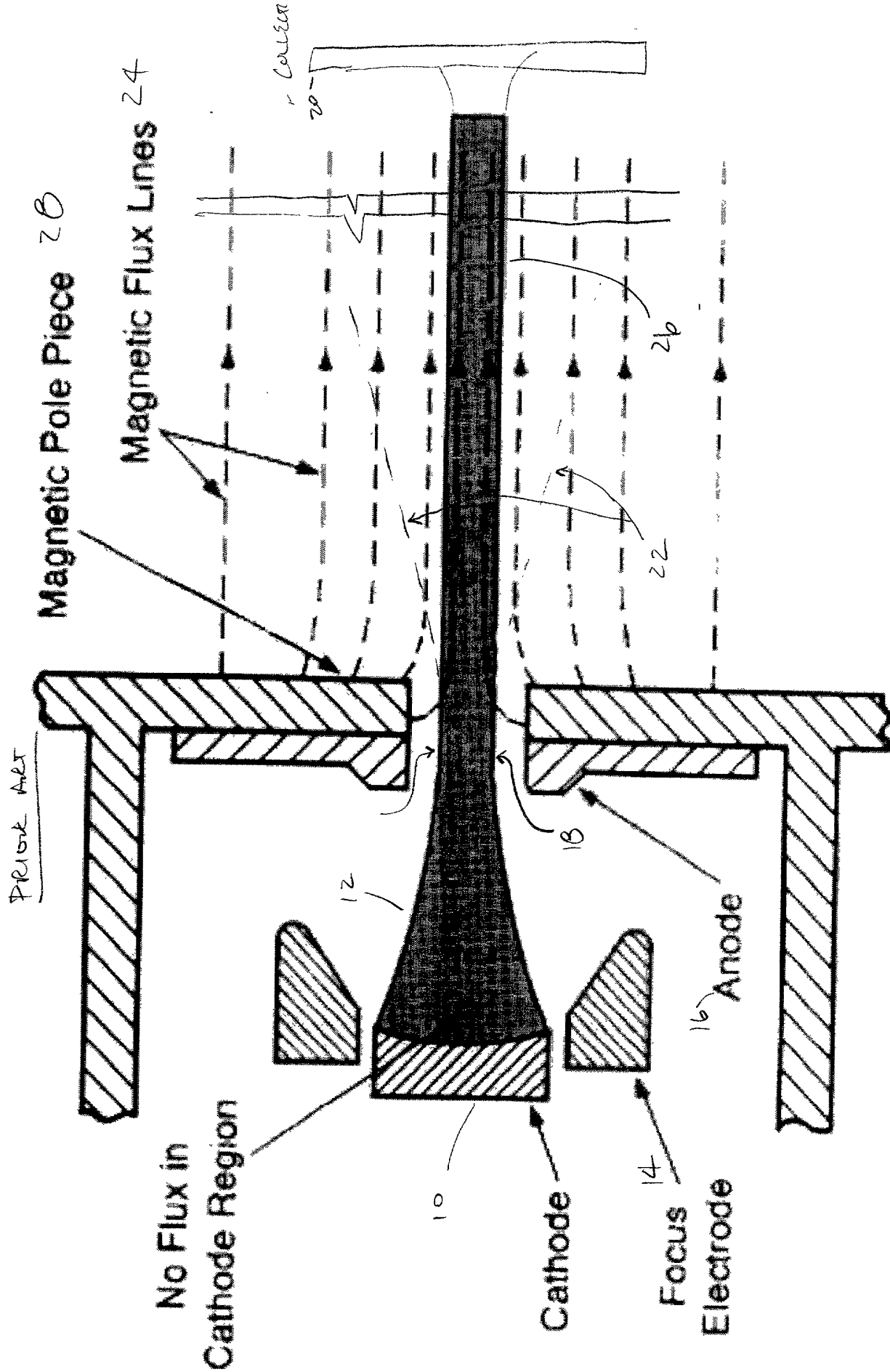
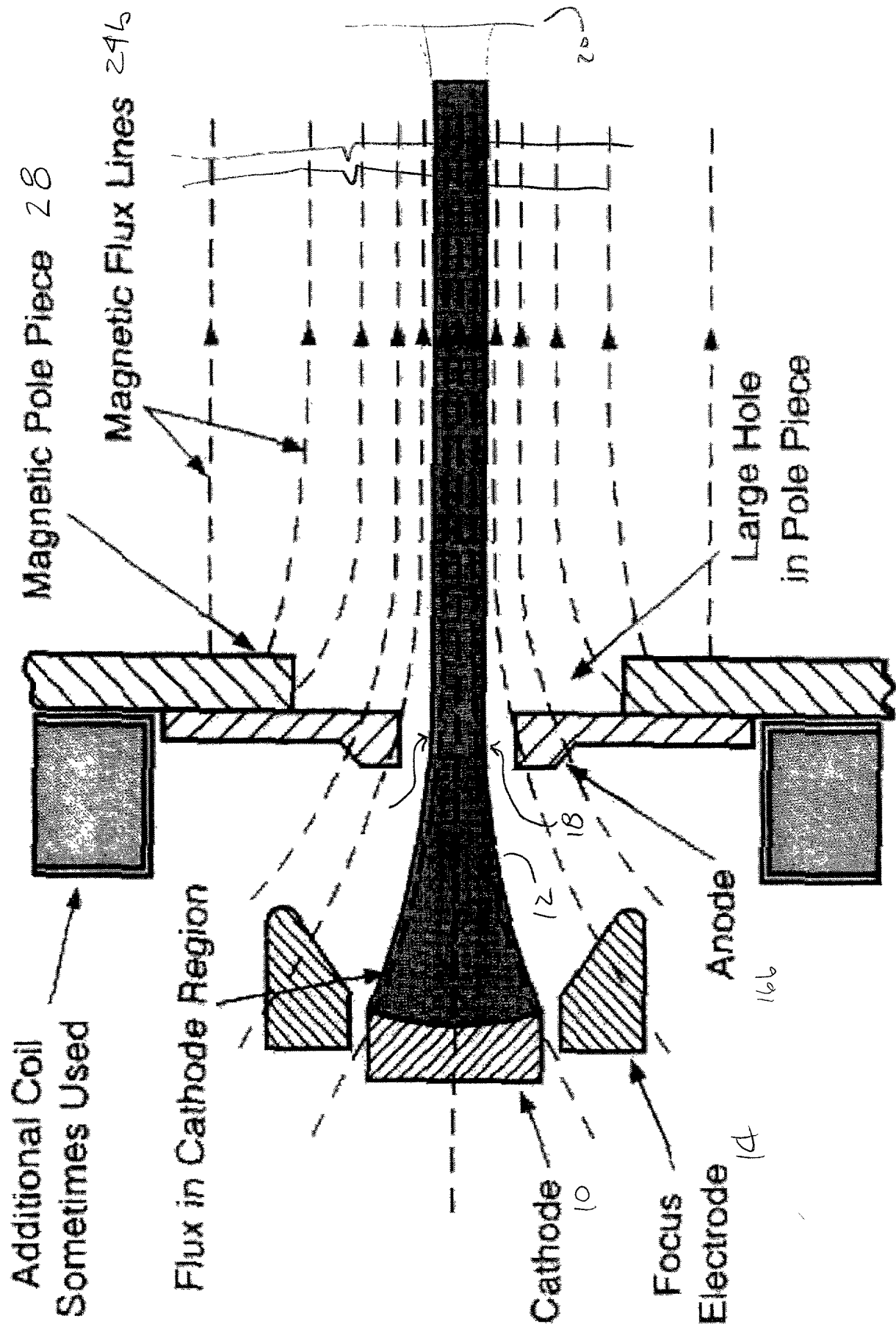
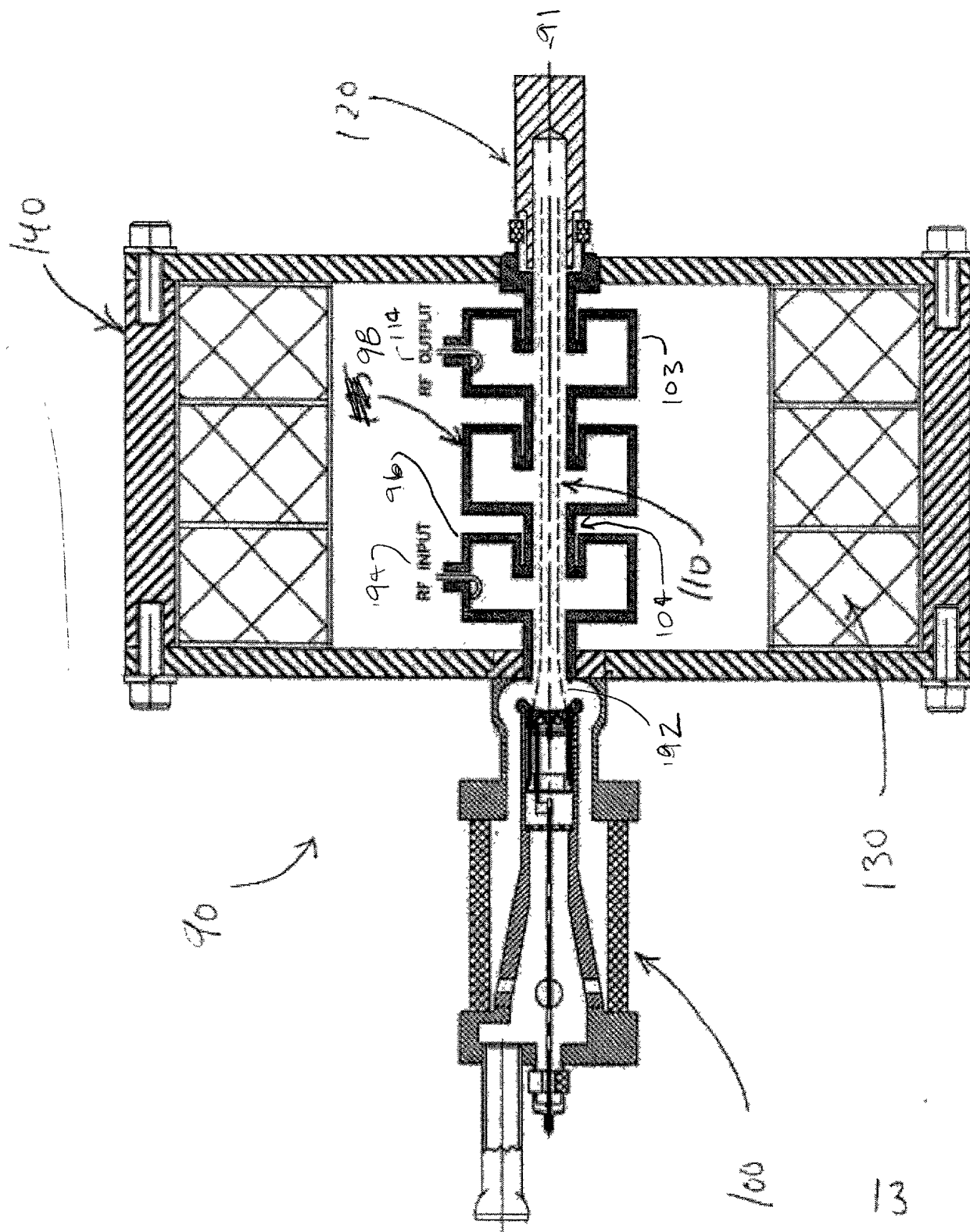


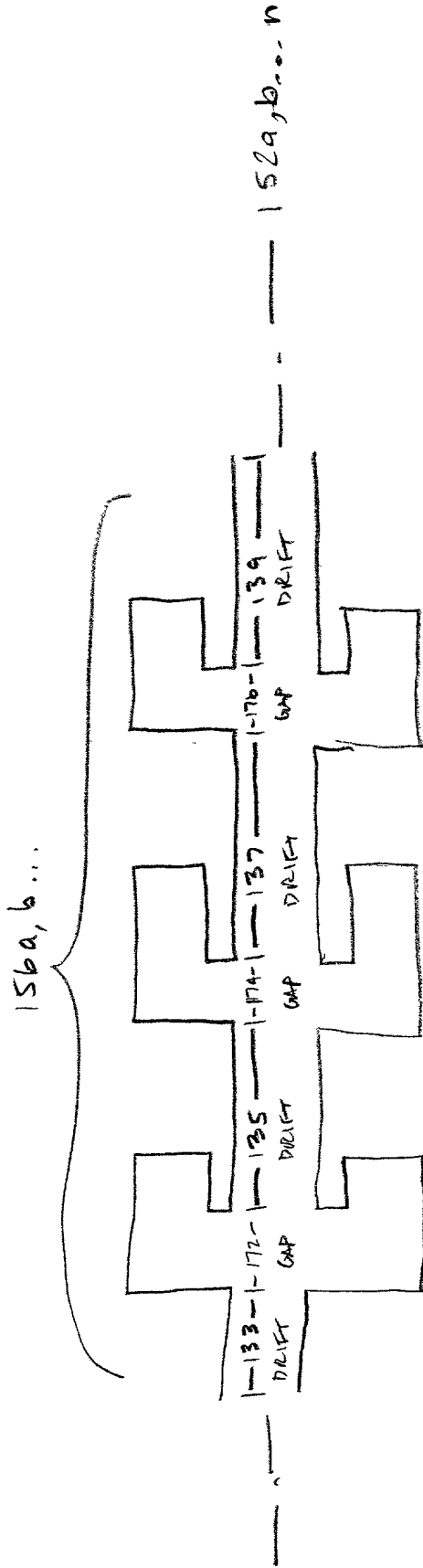
FIGURE 2
CONFINED FLOW
P. 1000-1000-1000





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FIG 4-1, DETAIL OF BEAM TUNNEL



4a

FIGURE 1a

Figure 1a

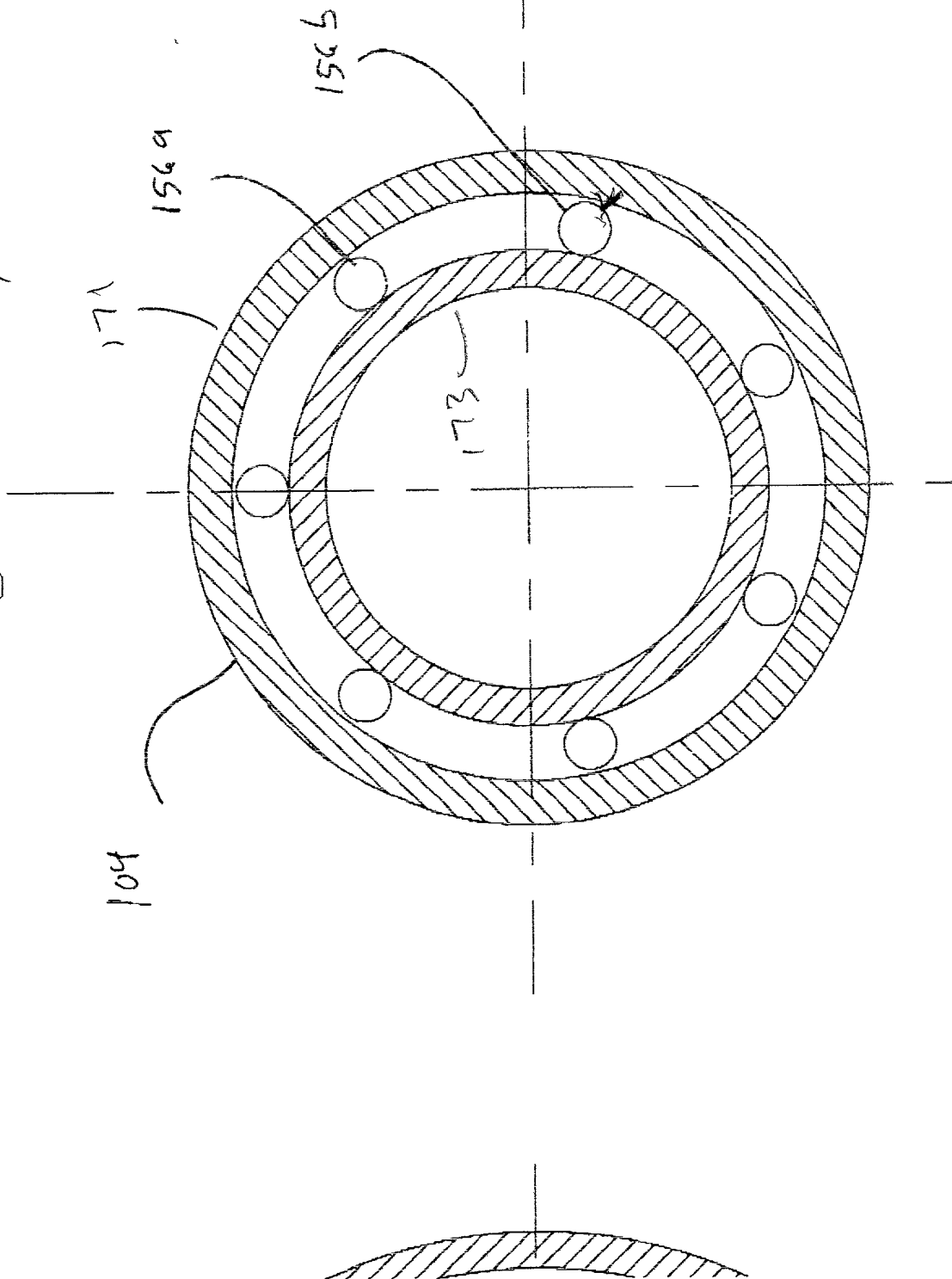


Figure 4B

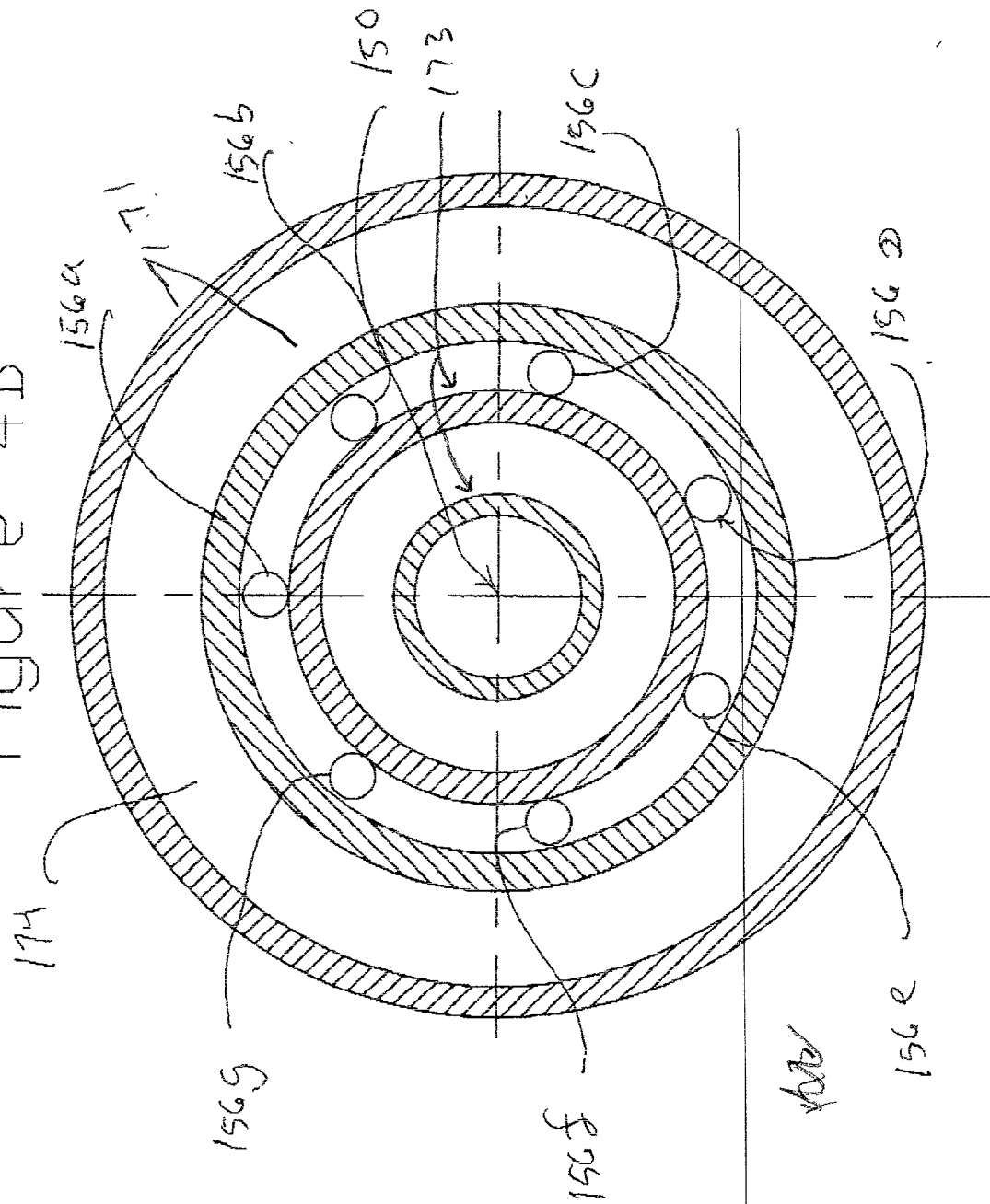
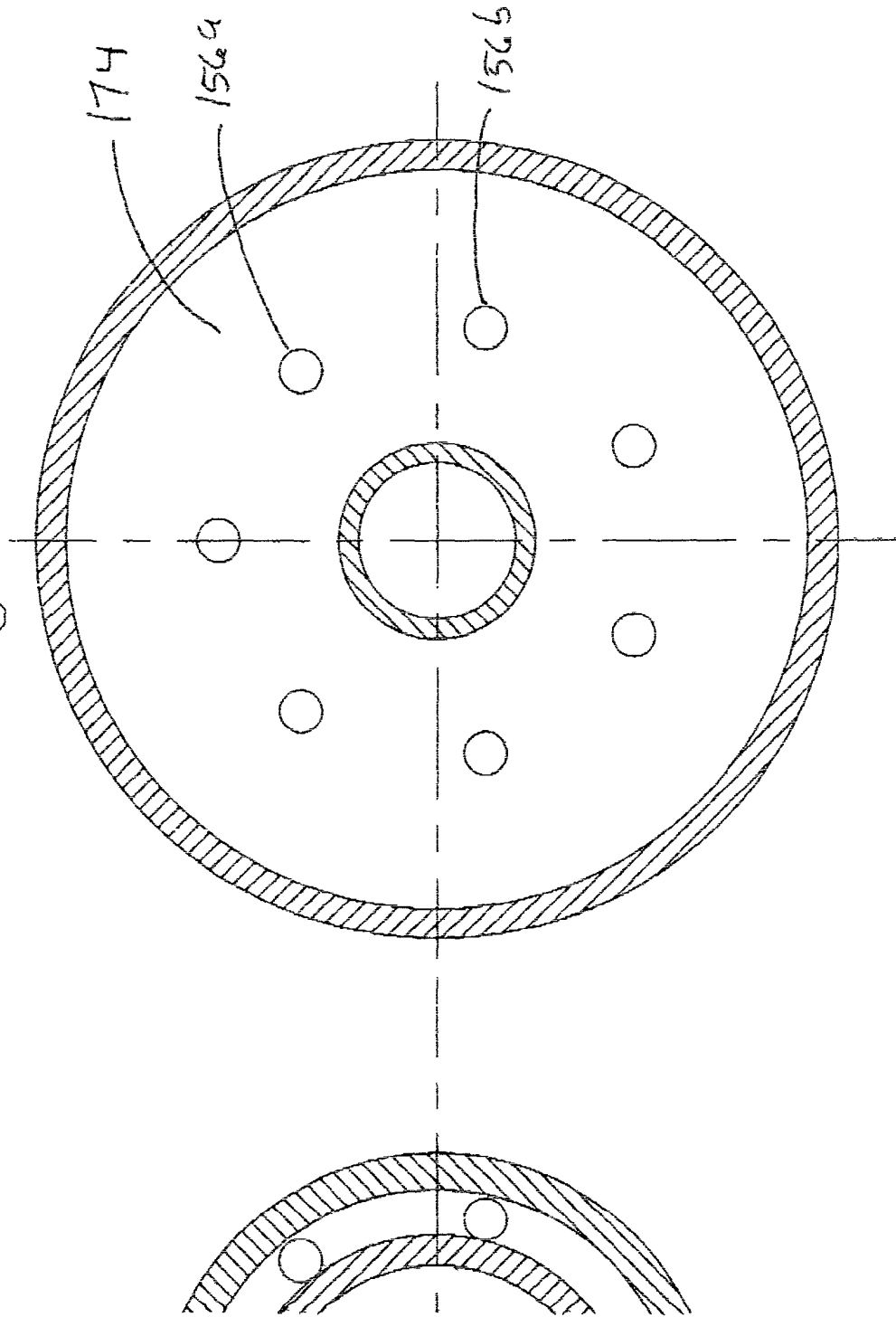
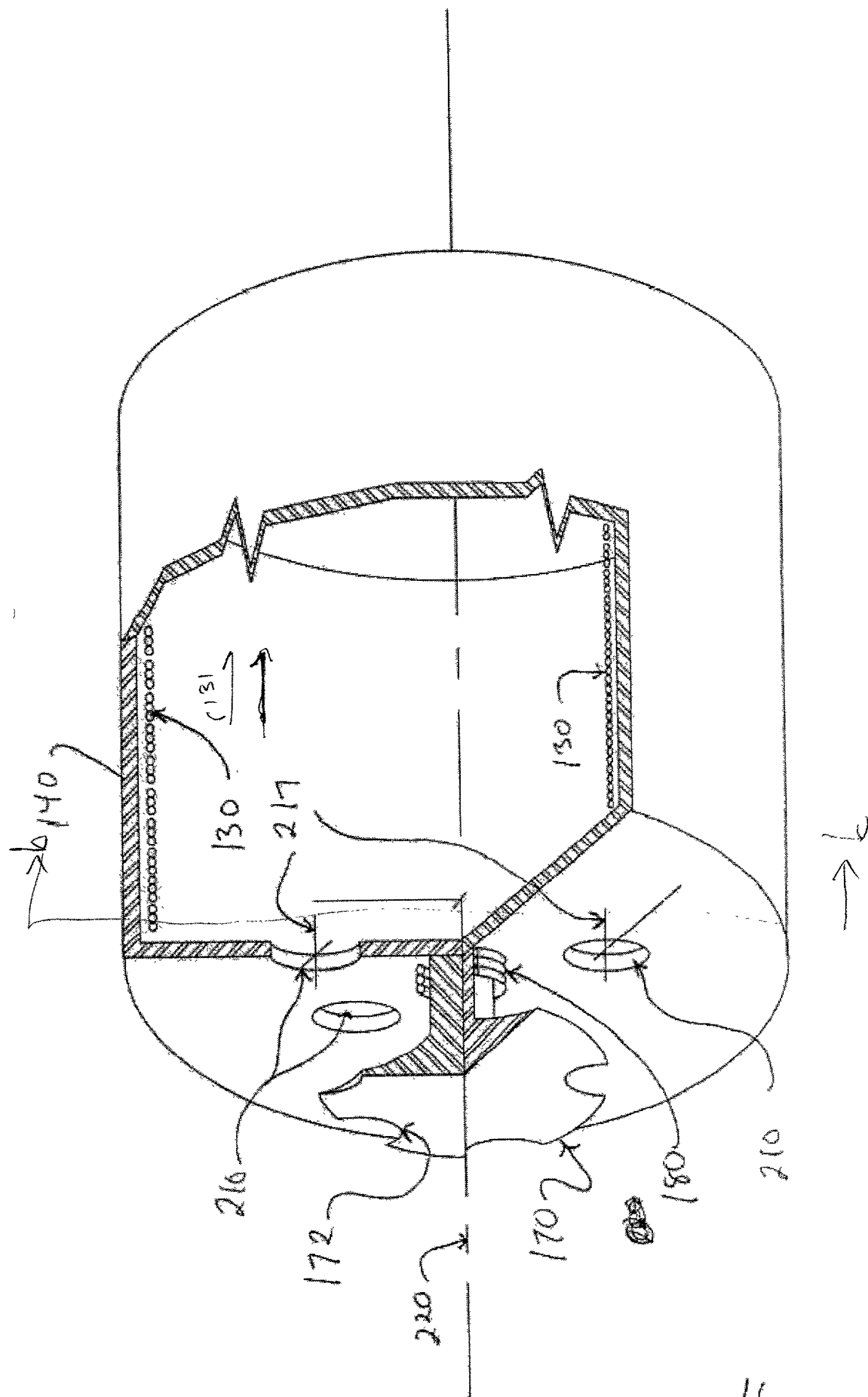
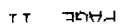


Figure 40c



FS 6a



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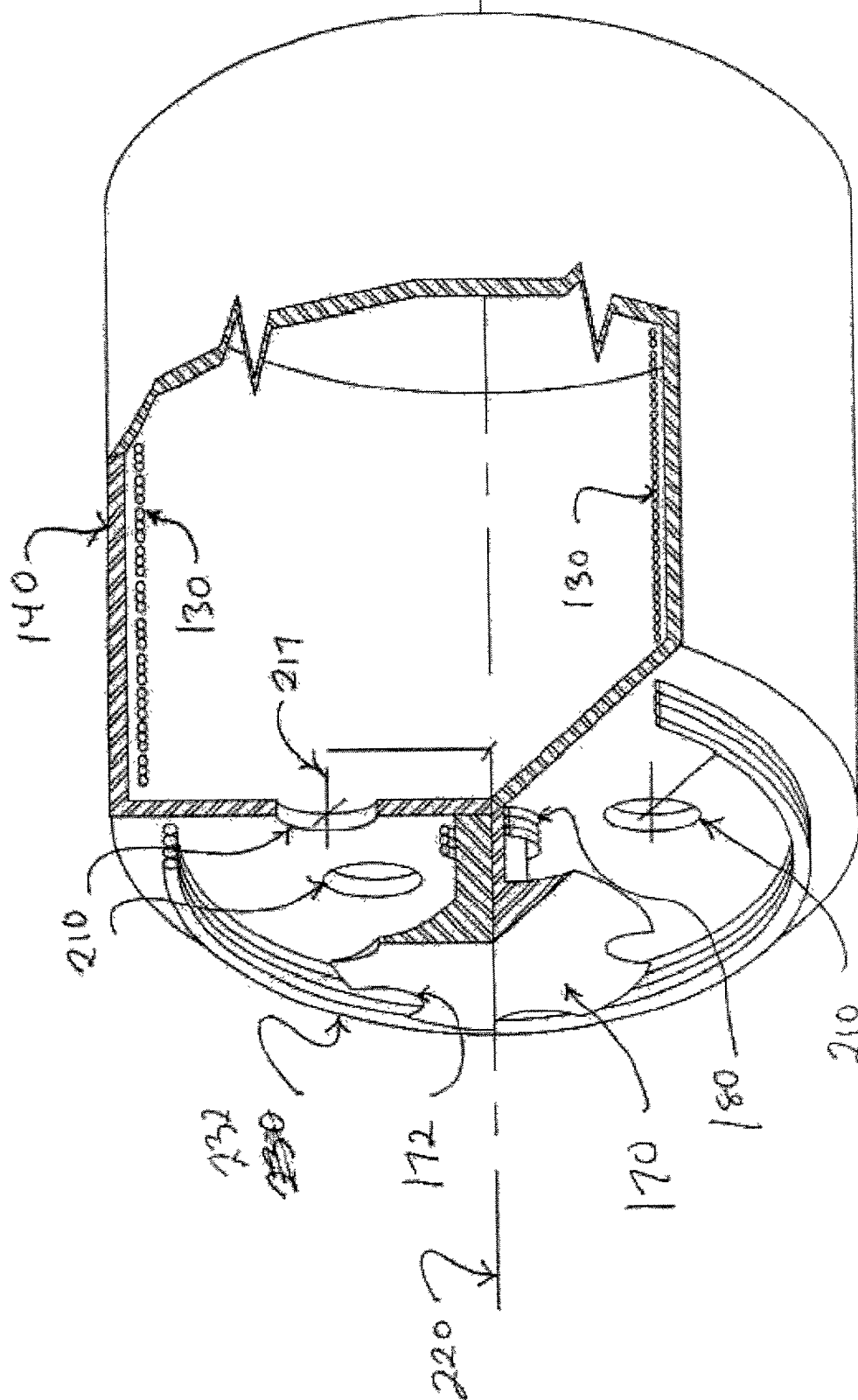
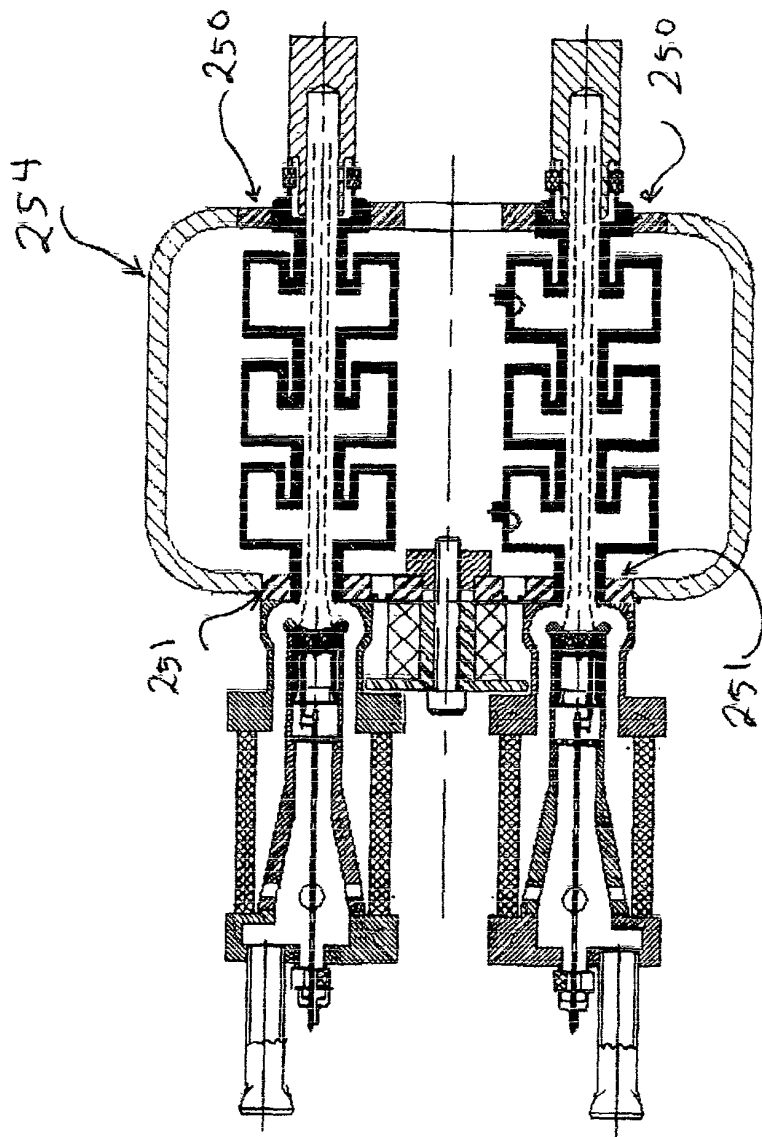
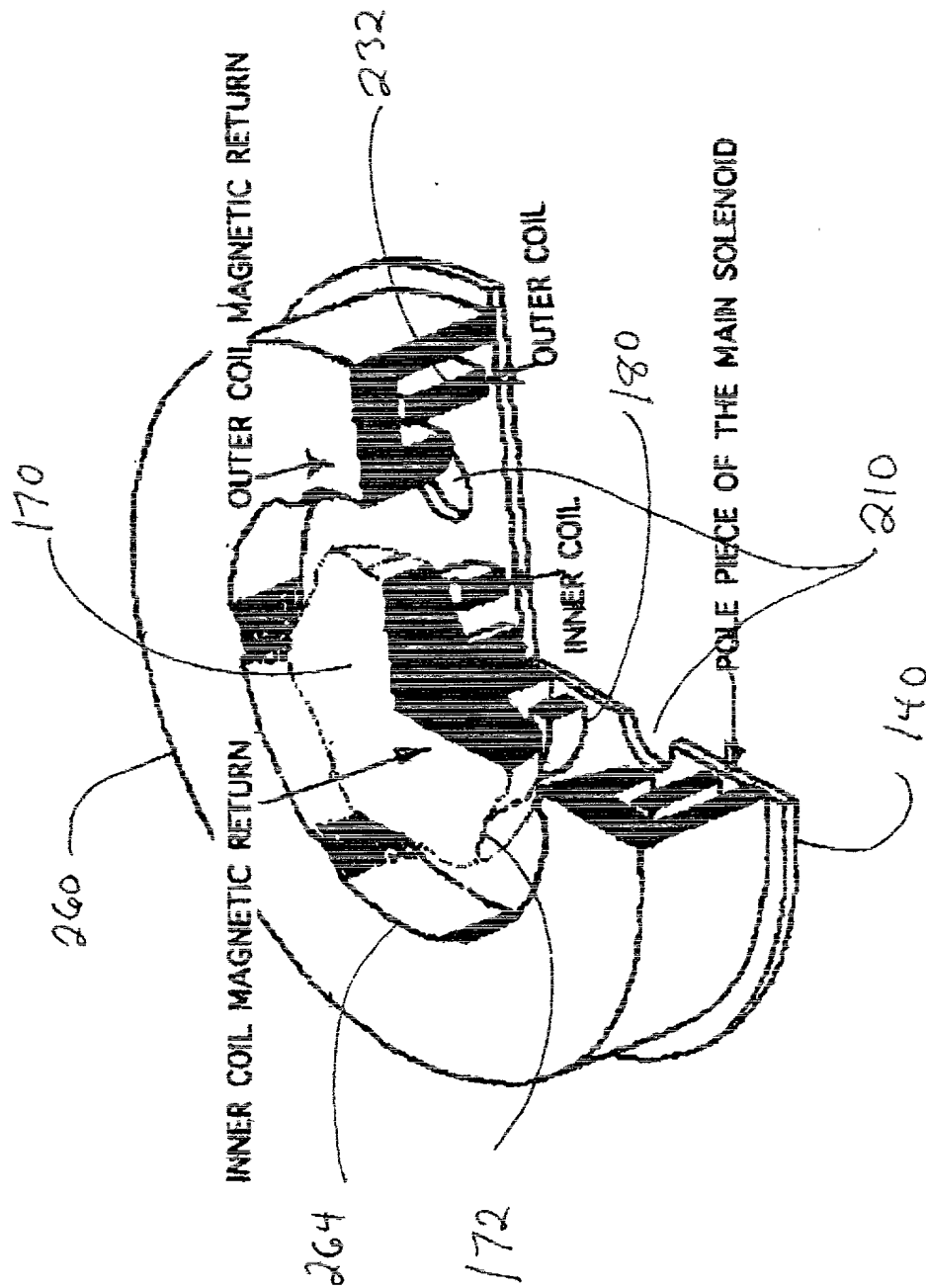


Figure 4



Alternate embodiment of Figure 4 with iron 140 and electromagnet coils 130 replaced by iron 250, 251 and permanent magnet 254.

Figure 10



Declaration for Patent Application under 37 CFR 1.63

As the below named inventor, I hereby declare that my residence, post office address, and citizenship are as stated below next to my name, and that I believe that I are the original, first, and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention, the specification of which is attached hereto and which has the following title:

"Electron Gun For A Multiple Beam Klystron Using Magnetic Focusing"

I have reviewed and understand the contents of the above identified specification, including the claims. I acknowledge a duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby declare that all statements made herein of my own knowledge are true and all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Title 18, United States Code, Section 1001, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Please send correspondence and make telephone calls to the Agent identified below.

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PTO Reg. #39,137

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650-494-9162

POWER OF ATTORNEY BY ASSIGNEE
UNDER 37 CFR 1.31

To the commissioner of Patents and Trademarks:

The undersigned assignee of the entire interest in application for
letters patent entitled:

Electron Gun for Multiple Beam Klystron using Magnetic Focusing
and having the named inventors:

R. Lawrence Ives
George Miram

hereby appoints the following agent to prosecute this application and to
transact all business in the Patent and Trademark Office connected
therewith; said appointment in accordance with the provisions of 37 CFR
1.32:

Jay Chesavage, Reg. No. 39,137

Direct all telephone calls to 650-494-9162.

Address all correspondence to:

Jay Chesavage
3833 Middlefield Rd.
Palo Alto, Ca. 94303

Assignee: Calabazas Creek Research Inc.

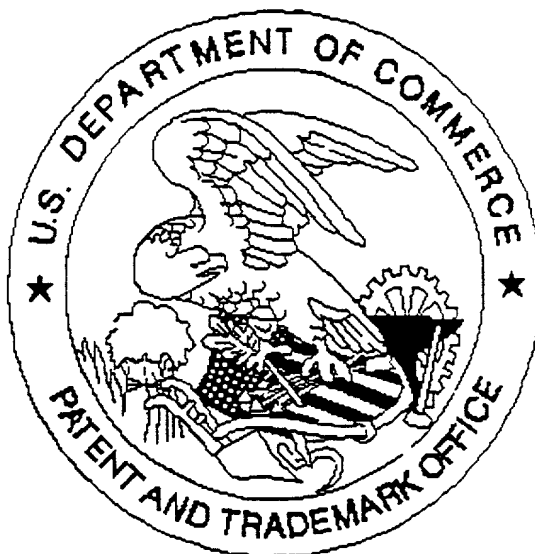
By: R. Lawrence Ives, President

Signature: R. Lawrence Ives

Address: 20937 Comer Drive
Saratoga, Ca. 95070

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